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DESIGN STUDY REQUIREMENTS FOR A LUNAR SOFT LANDING SPACECRAFT (SCIENTIFIC MISSION: SURVEYOR)

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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I. SCIENTIFIC OBJECTIVE OF MISSION

The general scientific objective of this mission is the investigation of a limited area of the Moon. The general requirements of the mission and the lunar environment to be assumed for the purposes of the study appear in Sections II and III, respectively. Those experiments which are presently being seriously considered for the mission appear in Sections IV and V. For the purposes of this design study, a selection of experiments is given in Section VI in order to define preferred scientific payloads as they relate to vehicle capability.

It must be understood that the selection of payloads mentioned above, the requirements of particular instrumentation, the position of the interface in relation to a given instrument, and the general requirements of the scientific mission must be expected to change, although every attempt will be made to reduce the number and significance of such changes. Following the second technical status presentation, the final changes to the scientific mission for the purposes of the design study will be determined. This is not meant to imply that the various aspects of the scientific mission will have ceased to evolve; these aspects will certainly continue well after the termination of the design study phase. It is meant to promote a definitive state of design study under uniform and fairly realistic boundary conditions. Clearly, a certain degree of flexibility should be maintained with respect to the scientific mission.

II. GENERAL REQUIREMENTS

The following listing presents the general requirements for this mission:

1. Single Scientific Payload. For the purposes of this study it is to be considered that essentially one scientific payload will be arrived at for all seven spacecraft.
2. Lifetime. The minimum lifetime requirement is one month. There will be a requirement for lunar night operation on certain experiments.
3. Landing Site. For environmental reasons, landing in one of the maria-like regions will be a requirement. No other requirements will be made to land at sites not normally a consequence of the trajectory and terminal maneuver mechanization unless such capability becomes available as a reasonable consequence of the design.
4. Lunar Lighting. Although it is not presently a strong requirement, it appears desirable to perform much of the surveillance in the visual region as soon as possible after landing. Therefore, the landing should occur on a lighted portion of the Moon.
5. Landing Impact. Instrumentation will either be designed or packaged to withstand 100 Earth g's at lunar landing.
6. Retro-Rocket Site Contamination. At present no requirement will be made for placing the scientific instrumentation on uncontaminated areas. It is necessary that as the study program progresses the nature of the contaminants be ascertained.

7. Sterilization. Instrumentation to be supplied through the Jet Propulsion Laboratory will be internally sterile and capable of sustaining an ethylene oxide surface sterilization. Although it is desirable that all instrumentation be capable of withstanding a heat-soak type of sterilization (e.g., 125°C for 24 hr), it is almost certain that there will be exceptions to this procedure.

   Where possible, an estimate of a particular instrument's ability to withstand a heat-soak sterilization will be made. In general, however, such information will not be available during the course of the design study.

   The spacecraft contractor will be responsible for sterilization procedures compatible with instrumentation supplied through the Jet Propulsion Laboratory.

8. Radiation Background Control. Certain experiments mentioned in Section V will be sensitive to the radiation background during operation on the Moon. The spacecraft contractor will be responsible for the reduction of this background to levels compatible with the operational requirements of the instrument. The natural radiation contributions that are to be assumed in determining this problem are given in Section III, item 11.

III. LUNAR ENVIRONMENT

In order to specify a relatively low-risk environment for the spacecraft, it is required that the landing site be in one of the maria-like regions. For purposes of the design study, the following lunar environmental conditions are to be assumed:

1. The effects of certain factors in the environment will be small and will not be considered as design conditions. These factors are: (1) meteorite particles, (2) magnetic and electric fields, (3) electromagnetic radiation, except the range affecting heat balance, and (4) corpuscular radiation.
2. The lunar atmosphere is a vacuum.
3. Slopes greater than 15 deg will not be encountered. Although this is the assumed design condition, it will be necessary to ascertain the probability of spacecraft survival if slopes greater than 15 deg are encountered.
4. Protuberances larger than 10 cm will not be encountered.
5. The hardness of the surface will range from that of soft wood to that of very hard rock. The uncertainty assumed here implies that landing devices which depend upon doing work on the lunar surface material must be carefully planned.
6. Maps based on pictures taken from Earth are in the process of being prepared for the area from 40 to 48 deg east longitude along the Moon's equator. These maps are primarily for the earlier rough landing spacecraft, but, insofar as landing sites

may coincide, these maps will be considered the primary source of information for these missions. As new landing sites evolve, additional maps will be prepared through JPL. Maps of the expected impact areas come largely from the study of Earth-based telescopic photographs. The accuracy of these photos does not resolve two points on the lunar surface closer than one-third of a mile. Further, the visible surface is treated as a flat disk.

The Moon is being mapped photogrammetrically by the U.S. Army Map Service. These maps are drawn to a scale of 1:5,000,000 and plot a large number of tie points on the lunar surface to an absolute distance from the lunar center to an accuracy of ±2100 ft through the use of stereophoto pairs.

The U.S. Air Force is also preparing a set of maps which are drawn to a scale of 1:1,000,000, using the lunar atlas of photographs supplied by Professor Kuiper. (These photos are printed at a 1:1,400,000 scale.) These larger-scale maps are not intended to maintain the expected increase in mapping accuracy over the 1:5,000,000 Army map; rather than precise photogrammetric accuracy, their purpose is to obtain as much pictorial accuracy as can be obtained by a compilation of known photos. There are 1000-ft contours drawn on the map from an arbitrary ground level, but these are a guide rather than a real measurement.

In addition to use in these mapping efforts, the U.S. Geological Survey has used the photographs as well as radar and other information to compile a map which attempts to describe surface structure in terms of selenological features. These maps are also drawn to a scale of 1:1,000,000.

The present schedule for the USAF maps is as follows:

1 August:	The region from 30 to 50 deg east longitude and 0 to 14 deg north latitude (in the region of the crater Kepler) without contours. A copy of this map will be forwarded as an example.
15 September:	The same region with contours.
1 December:	The region to the south with contours.

7. The lunar surface temperature falls from a maximum of around 400°K at the subsolar point to a nighttime value of approximately 120°K. The thermal conductivity of the lunar material is less than 10^{-4} cal cm^{-1} sec^{-1} $(°C)^{-1}$. The albedo on the maria is assumed to be 0.07.

8. Surface dust conditions are uncertain. Although it is necessary to consider this effect, it should not be considered a primary design condition.

9. The frictional properties of the lunar surface are uncertain.

10. Radar Reflectivity Model. Lunar reflection properties (wavelength = 1 m to 10 cm) are as follows:[1]

Average η	0.01 to 0.0025
Average μ'	approx 1
Average ϵ'	1.20 to 1.40
Average θ	3.5 to 7 deg
Average depth of layer	several meters
Average density of layer	(0.05 to 0.10) density of solid silica
$P(\theta > 30°)$	$\simeq 0.01$
Base line	1 meter

The ratio of power in the scatter component to power in the specular component (cpr) is about 0.15 for ranges in excess of 170,000 km. An estimate of the value of cpr as a function of distance from the surface (isotropic antenna) is given by

$$\mathrm{cpr}(R) = \mathrm{cpr}_{\infty}\left(1 + \frac{\rho}{R}\right)$$

where R is the range to surface, ρ is the radius of the Moon, and $\mathrm{cpr}_{\infty} = 0.15$.

For ranges less than 100 km, the surface is estimated to behave essentially as a scatterer. A sample calculation

[1] θ = angle of slope of surface with respect to local horizon; μ' = relative permeability; ϵ' = relative permittivity; $P(\theta)$ = probability of: θ; η = average reflectivity = radar cross section (scatter component)/Lambert cross section

indicates that the scattering cross section for a full beamwidth of 10 deg at an altitude of 100 km would be about 70 db (normalizing factor, 1 square meter) if the pulse width were greater than 1 μsec. The power required per cycle for an snr = 20 db is 4 dbw/cycle when the wavelength = 0.1 meter. Thus, peak power of about 100 watts would be necessary when the pulse width is 1 μsec.

11. Although, as mentioned earlier in this section, radiation not involved in the heat balance is not to be considered as a spacecraft design condition, it may be necessary to consider its contribution to the total background in which a given instrument operates. For this purpose the following radiation characteristics are to be assumed:

    a. Primary cosmic rays: 1.3 per cm^2 per sec.

    b. Back scattered neutrons produced by (a): 0.3 per cm^2 per sec.

    c. Natural lunar radioactivity (gamma radiation from K, U, and Th): -0.03 to 0.08 per cm^2 per sec.

    d. Induced gamma radiation from (a): 0.5 per cm^2 per sec in the range from 0 to 2 mev.

    e. An estimate for the cosmic-ray-induced gamma radiation from the spacecraft would be twice (d).

IV. INSTRUMENTATION TO BE INCLUDED IN THE DESIGN STUDY BY THE SPACECRAFT VENDOR

In Revision 1 of JPL Technical Memorandum No. 33-13 it is stated that "the design of certain types of instrumentation and supporting structure will be highly dependent on the over-all design of the landing vehicle. In such cases, the design study will include these items as part of the design study." Consistent with this statement, the following instrumentation shall be included in the design study.

A. Visual Surveillance System

It is proposed that a visual surveillance system be incorporated in the soft-landing vehicle with the primary mission of surveying the lunar surface. The experience of the Jet Propulsion Laboratory suggests that only vidicon-type systems need be considered. The lunar surveillance system should have the capability for viewing either in the vicinity of the vehicle or the full horizon through all local azimuth angles. The system should be able to view angles to within 45 deg of the vertical. The linear resolution of the system should be approximately 1 mm at a distance of 2 to 4 meters from the spacecraft with an equivalent angular resolution at greater distances.

A further improvement in the TV system would be a high resolution capability of 0.1 to 0.01 mm for a few areas in the vicinity of the spacecraft which have been selected from the area already viewed by the above system. In some experiments it is desirable to use the TV system for monitoring purposes. Such requirements are mentioned in Section V.

A further possible use of a TV system is to survey the landing site from the incoming spacecraft. Such a surveillance would be useful if a surface resolution of 1 meter could be obtained for the final picture before landing.

It is emphasized that operation on the lunar surface is the primary function of a TV system. Weight and power required for approach surveillance will be considered with the balance of the scientific instrumentation.

B. Lunar Drill

The general objectives of drilling a hole in the lunar surface are:

1. The determination of the hardness of the lunar material as a function of the depth of penetration.
2. The acquisition of samples for composition and biological analysis from various depths in the hole.
3. The use of the hole for physical measurements. The performance characteristics necessary to meet these objectives are given below.

The drill should be capable of drilling a hole 18 in. deep in Harris granite and 5 ft in Berea sandstone with the diameter and side wall regularity of the hole being such that free passage to the bottom of the hole of a geophysical probe (Section V) 18 in. long and 1.5 in. in diameter will be assured upon removal of the drill.

The drill should be capable of recovering cuttings for analysis at regularly spaced intervals of depth. The size of the interval should vary, depending on some indication of the depth of the hole that is likely to be achieved.

The quantity of cuttings that are recovered must be sufficient to provide samples, after handling and preparation losses, to any apparatus that may require them.

The mass of material that can be recovered from a given volume of hole will, of course, depend on the density of lunar material. It will be a satisfactory design condition to assume that, if the material is hard enough to limit the final hole depth to 18 in., the mass density will be 3 gm/cc and that the density will vary with the hardness of material in such a way that an equivalent mass will be contained in any deeper hole. The drill and sample recovery system should function in such a manner that, if the total mass of material in the hole is less than that assumed above, it will result only in a reduced number of samples.

The operation of the drill should be monitored in such a way that a maximum knowledge of the physical parameters of the lunar material as a function of depth is gained. The particular drill functions to be monitored will be dependent on the type of drill that is chosen and its tested performance on simulated lunar material under simulated lunar operational conditions.

The need for a casing to the drill hole cannot be stated without consideration of the rest of the drill and sample recovery system design. The possibility of hole collapse should not in itself be considered a sufficient reason to case the hole. If casing the hole is the most reasonable way to ensure sample recovery, then a casing which can be retracted after emplacement of the geophysical probe should be incorporated. If sample recovery does not require casing, then the hole should not be cased, since possible callapse of the hole, while impairing placement of the geophysical probe in the drill hole, will generally mean that the probe can be successfully placed by other means.

C. Manipulation Requirements

Special operations will be required to place certain of the experiments in locations away from the body of the spacecraft. This may be necessitated either to sample uncontaminated lunar material or to minimize interference by other operations. Similar functions are also required to move instrumentation, perhaps sequentially, in and out of the drill hole. Manipulation is also needed with some types of experiments in order to gather, prepare, and locate samples so that analysis can be accomplished.

As far as possible, the need for special manipulations is included with the descriptions of experiments in Section V. Trade-off studies should be made in the design study in order to choose between (1) moving the samples to fixed analysis equipment, (2) sequentially relocating the analysis equipment, or (3) a suitable combination of these two.

V. INSTRUMENTATION FURNISHED THROUGH JPL

A. Lunar Surface and Subsurface Measurements

The present recommendation for the measurement of lunar physical parameters is that the Surveyor include three separate subsystems for this general type of measurement and that these subsystems make redundant measurements in different situations. The situations are: (1) on the lunar surface, (2) within a drill hole or a hole prepared by a shaped charge, and (3) instrumentation to be oriented with the local vertical and driven into the lunar surface by mechanical means or by a small slow-burning charge.

Instrumentation for situations (2) and (3) would be identical, but the manipulation and orientation requirements differ for the two situations. This redundancy in instrumentation is recommended for several reasons. The instrumentation is being studied with very little knowledge of the Moon available; thus choices as to the most desirable situation tend to be arbitrary. The quantities to be measured are basic parameters such as density, thermal properties, and acoustic velocity and pertain to many areas of lunar study and investigation. In general, the sensors required for these measurements are lightweight and simple; the problem is centered on obtaining proper contact with the lunar material and on the interpretation of data obtained by the sensors. Measurements made on the lunar surface do not depend on successful operation of other systems such as a drill, but they may be very difficult to interpret if the degree of coupling between the sensors and the surface is not known. Measurements to be made within a hole in the lunar surface may be completely negated by failure of the hole-producing mechanism. Again, the degree of coupling between the side wall of the hole and the sensors is difficult to define without prior knowledge of the nature of the lunar material. Instrumentation to be driven into the lunar surface is chosen specifically to provide subsurface data independent of a hole-producing mechanism and to ensure good contact between the sensors and the lunar material. Instrumentation for all three situations should not exceed approximately 15 lb, not including cabling or instrumentation for positioning subsurface sensors. Details of each instrumentation subsystem are as follows:

1. <u>Instrumentation Subsystem for Operation on the Lunar Surface</u>

   1. General Functions and Dimensions[2]

      a. Density measurement: the proposed method of measuring density utilizes the gamma-gamma logging technique. The intensity of gamma radiation transmitted by a known thickness of material from a source emitting radiation of known intensity and character is measured using a GM counter. The density is linearly related to the log of the transmitted intensity. Background levels are monitored without the source.

      b. Acoustic velocity measurement: the compressional wave velocity is the most easily measured quantity. Accurate measurements of the arrival times of the waves generated by a pulsed acoustic source (dynamite cap) are made at two acoustic detectors, or receivers. The source and detectors are placed in known orientations and positions.

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[2]Over-all subsystem dimensions are 1 ft in diameter by 6 in. in height. The separate acoustic sensor is 1 in. in diameter and 1.5 in. in height. The acoustic source and shield for six shots consists of source 0.5 in. in diameter and 2 in. long, with attached shield 3 by 2 by 1/8 in. (Fig. 1).

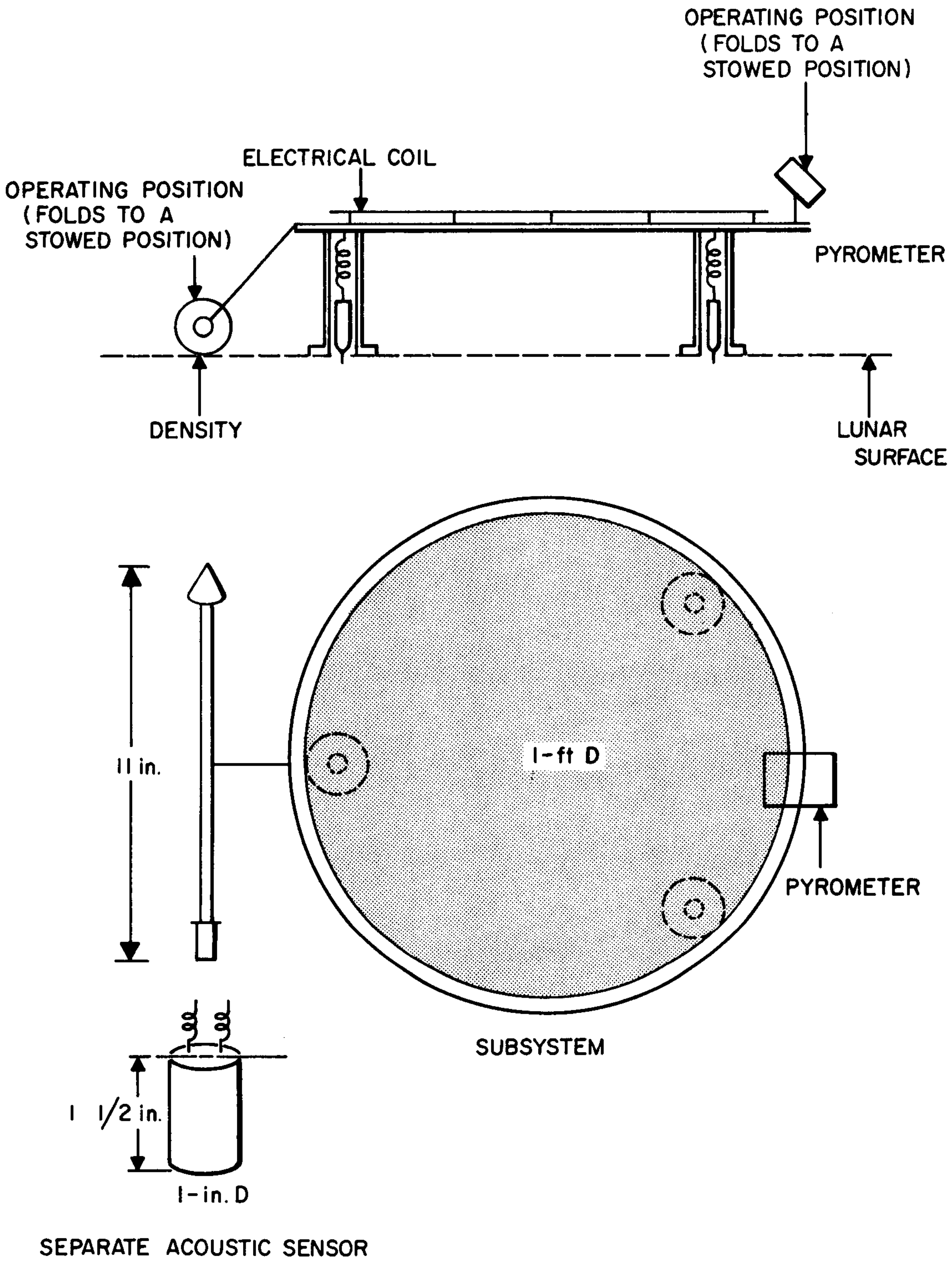

Fig. 1. Functional Diagram of Instrumentation Subsystem for Operation on the Lunar Surface.

c. Magnetic permeability and electrical resistivity: the proposed measurement techniques for these quantities employ a common instrumentation system. The instrument consists of a three-coil system using a bridged circuit. The bridge is balanced and then placed near the lunar material which unbalances the bridge. The properties of the material are determined by observing the resistance charge necessary to rebalance the bridge. A mutual inductance bridge of the Carey-Foster type will be used.

d. Thermal measurements: the principal quantities of interest are lunar surface temperatures, thermal conductivities and diffusivities of surface and subsurface materials, and subsurface temperature gradients. The difficulties encountered in obtaining reliable thermal measurements using thermocouples, resistance thermometers, and thermistors have led to consideration of the use of a radiation pyrometer for lunar surface temperature measurements.

e. Hardness measurements: measurement of surface hardness is to be made by three accelerometers individually housed in needle-nosed cylindrical packages spring-mounted to the subsystem. Deceleration of the package as it impinges on the lunar surface is related to the indentation hardness of the surface material. Deceleration curves so obtained may be interpreted by comparison with curves obtained with known Earth materials.

2. Environmental Requirements

a. Operating environment: the subsystem is designed to survive the lunar environment as specified in TM 33-13 with the following additional constraints:

(1) Radiation environment allowed at density geiger counter: maximum of 500 gammas per cm^2/sec and 15 electrons ($\geq$ 1 mev) per cm^2/sec.

(2) Tolerable magnetic field: 0.25 gauss or less.

b. Nonoperating environment: same as operating environment without the radiation constraint.

3. Weight Breakdown

a. Density: 2 lb 10 oz (including monitoring counter).

b. Acoustic velocity: 1 lb 7 oz total, 3.5 oz per sensor and 1 lb for 6-shot source and shield.

c. Magnetic permeability: 6 oz.

d. Resistivity: included in (c).

e. Thermal: 6 oz.

f. Hardness: 3 oz (1 oz per accelerometer).

4. Total Weight

a. Subsystem (above sensors plus structure but excluding leads to spacecraft): 9 lb.

b. Separate acoustic sensor: 3.5 oz.

c. Acoustic sources and shield: 1 lb.

5. Required Orientation. Subsystem must be in contact with the lunar surface on a designated face and must be exposed to direct sunlight. The subsystem shall be placed at a distance from the spacecraft great enough to avoid shadowing by the spacecraft. The subsystem is not to be shadowed until a time near that at which the spacecraft itself is shadowed by sunset. The time at which the subsystem passes into shadow must be known. The separate acoustic sensor must be in contact with the lunar surface on a designated face and be separated from the subsystem by 5 ft. The subsystem should be approximately 5 ft from the closest portion of the spacecraft. The spacing of the acoustic source from the subsystem is to be 10 ft and is to be 5 ft from the second acoustic sensor.

6. Required Knowledge of Orientation
   a. The orientation of the subsystem with the local surface and relative to local vertical must be known to within 15 deg.
   b. Separation distances:
      (1) Subsystem and spacecraft: between 5 and 10 ft, known to ±5%.
      (2) Subsystem and separate acoustic sensor: 5 to 10 ft, known to ±5%.
      (3) Subsystem and acoustic source: between 10 and 15 ft, known to ±5%.
      (4) Separate acoustic sensor and source: between 5 and 10 ft, known to ±5%.
      (5) Location of the acoustic source with respect to the straight line between the acoustic sensor located in the subsystem and the separate acoustic sensor. If the source lies on this line it is not necessary to

know the distance between the source and the sensors, but only the spacing between the two sensors.

c. TV view of surface emplacement area both before and after subsystem emplacement at an angle of illumination allowing a good estimate of surface roughness. The best available resolution should be used for these views. This requirement also applies to the separate acoustic sensor if it is placed on the lunar surface remote from the spacecraft. If the second sensor is mounted on one of the spacecraft legs, contact may be assured by a spring mechanism and TV views are not required.

7. Operating Power

a. Density:

(1) 10 microamps drain (log and monitor).

(2) 1000 volts dc of regulated power.

Range: 1000 ± 200 volts dc.

Tolerance: 1000 ± 2% volts dc.

Ripple: Tolerance depends on supply. At 60 cycles, 10 volts ripple is acceptable. In the kc range ripple should be less than 0.1 volt.

(3) Output impedance of power supply to be under 1000 ohms.

b. Acoustic velocity: none except power to detonate acoustic sources.

c. Magnetic permeability:

(1) 150 milliamp.

(2) 15 volts ac

Range: 15 ±50% volts ac

Tolerance: 15 ±5% volts ac

(3) 100-ohm input impedance to bridge.

(4) 1000 cycles +50%, -25% but known well enough to be compatible with data output.[3]

d. Resistivity: measured by instrumentation used for (c); no separate power supply.

e. Thermal: none.

f. Hardness: power to actuate release of accelerometer (3 accelerometers released in sequence, not simultaneously).

8. Time Per Operating Period

a. Density: 100 sec.

b. Acoustic velocity: 1 sec (starting at time of detonation of acoustic source).

c. Magnetic permeability: 60 sec (time to balance bridge and record resistance).

d. Resistivity: included in (c).

e. Thermal: continuous sensor operation.

f. Hardness: 3 sec (1 sec per accelerometer).

9. Number of Operating Periods

a. Density: 10.

b. Acoustic velocity: 6.

c. Magnetic permeability: 5.

[3]Output data form and resulting requirements on power supply depend on method chosen to balance the bridge.

d. Resistivity: same periods as (c).

e. Thermal: once an hour for 1 month with continuous sampling during day/night and night/day transitions (3 hours centered around sunset and sunrise).

f. Hardness: 1 per accelerometer (3 total).

10. Sample Preparation Requirements. None.

11. Manipulation Requirements

a. Alignment and placement of subsystem on the lunar surface with a designated face in contact with surface.

b. Placement of separate acoustic sensor with designated face in contact with surface. If separate acoustic sensor is mounted on one of the spacecraft legs, this placement might be accomplished by release of a spring mechanism designed to press the sensor against the lunar surface and also to act as a decoupling mechanism.

c. Placement of acoustic sources and shield.[4]

12. Data Output

a. Density: output is 2 volt negative pulses of 50-μsec duration, 50 - 1000 cps, load impedance of 500 kohms, range is 100 kohm to 1 megohm. Between 75 and 80 counts/sec correspond to a 1 gm/cc change in the density. An accuracy of ±8% in the density data received on Earth is required.

Measurement range: 0 to 4 gm/cc.

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[4] Spacing requirements are given in (6) of this section.

b. Acoustic velocity: output is 10 microvolts to 1 millivolt (50 cycles to 5 kc) with 300-ohm output impedance. The maximum allowable peak-to-peak noise in the input to the recording system is 1 microvolt. The waveform is desired. Measurement range: 300 to 20,000 ft/sec. Accuracy of data received on Earth is to be ±10% in lower velocity range and ±20% in upper velocity range.

c. Magnetic permeability:[5] measurement range (magnetic susceptibility) is 10 to 50,000 x 10^6 cgs. Required accuracy of data received on Earth is ±25%.

d. Resistivity:[5] measurement range is 10^6 to 10^{10} ohm - cm. Required accuracy in data received on Earth is 1 order of magnitude.

e. Thermal: output is 0.3 to 0.8 millivolt/°K. 150 millivolts is the total range and there is no bias. Recovery of data on Earth to 0.3 millivolt is required. Measurement range: 120 to 400°K.

f. Hardness: output is 10 millivolts per g, 50 cycles to 5 kc. 1 millivolt is the maximum allowable peak noise in the input to the recording system. Output impedance between 10 and 100 megohms. The waveform is desired. Accuracy of ±10% of the acceleration in the received data is required. (The g range of this device has not yet been determined.)

[5]Output data for both magnetic permeability and resistivity measurements depend on method chosen by the spacecraft designer to balance the bridge (see Fig. 2). Bridge characteristics are: R_1 = 20-kohms potentiometer continuously variable to zero; R_2 = 100-ohm, fixed; R_3 = 1000-ohm potentiometer variable in 200-ohm steps to zero; C = 0.01 μfd; accuracies: ±0.5% on R_1, R_2, R_3, and ±5% on C.

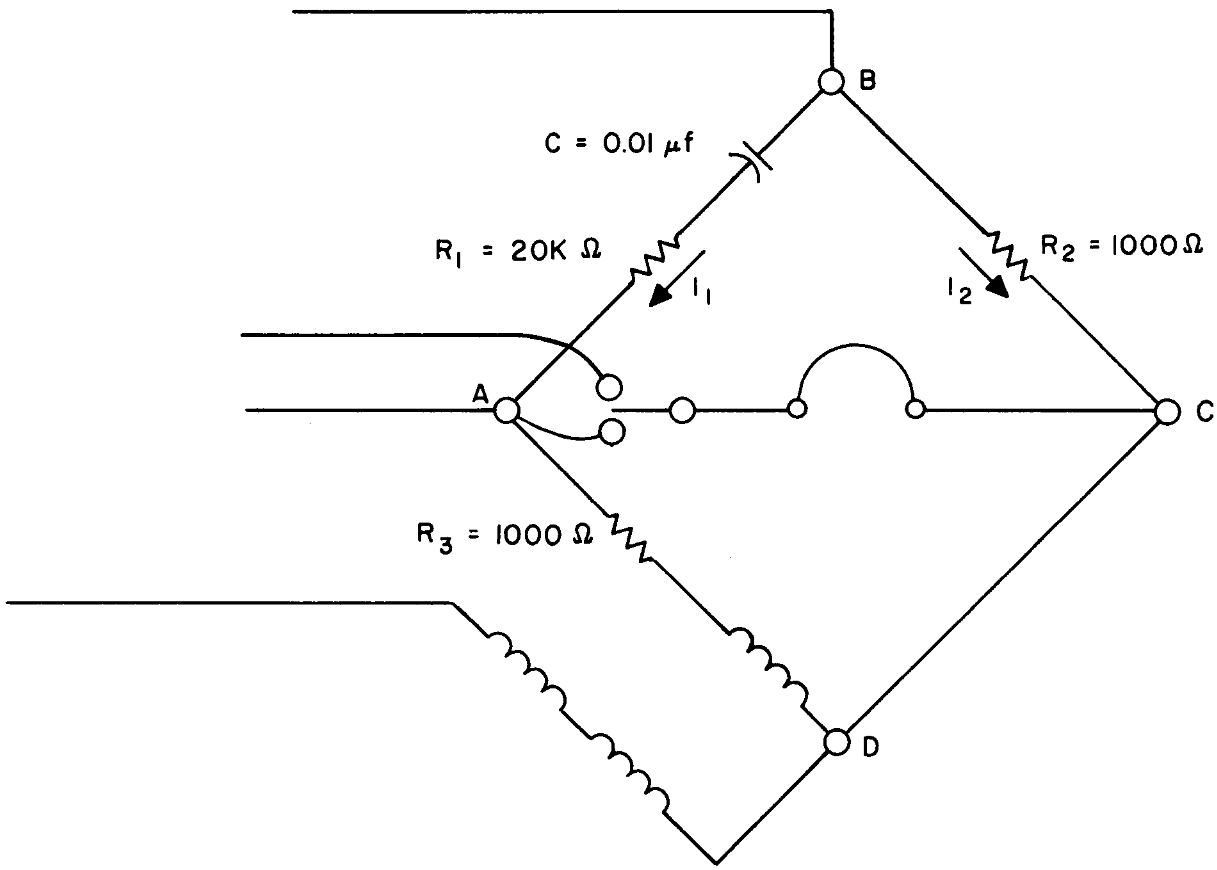

Fig. 2. Diagram of Carey-Foster Bridge Circuit.

13. Real Time Data Requirements. None.

Data storage is acceptable if accurate time measurements are included.

Time accuracy required for acoustic measurement is ±5 μsec on time of firing acoustic source, and 12.5-μsec uncertainty between arrival time at the two sensors.

14. Commands Required from the Spacecraft

    a. Commands to start manipulation and placement sequences previously described.

    b. Release of density sensor.

    c. Triggering of each accelerometer.

    d. Triggering of each acoustic source.

    e. Initiation of data sampling and storage, including commands to switch density to monitor for each measurement.

15. Operational Sequence

    a. Orient and emplace subsystem on lunar surface with high resolution TV views of emplacement area before and after emplacement.

    b. Orient and emplace separate acoustic sensor. TV views of emplacement area before and after emplacement are required unless separate acoustic sensor is mounted on a spacecraft leg and pushed against the surface by a spring.

    c. Lower density log from subsystem by command.

    d. Operate the accelerometers individually (3 in sequence).

    e. Operate density log: with 10 measurements total, at least one hour apart. Measurements to be made only at temperatures greater than 270°K. Each measurement to be followed as quickly as possible by reading from background monitor.

f. Placement of acoustic source, detonation of source, and operation of acoustic sensors. Measurements made 3 times during lunar day and 3 times during lunar night (separate measurements not closer than 10 minutes). Rise time of pulse to fire acoustic sources to be less than 2 μsec.

g. Thermal data: sample once an hour over day/night cycle with continuous measurements over day/night and night/day transitions (3-hour periods centered around sunset and sunrise).

h. Operate magnetic permeability and resistivity instrument 5 times, at least one hour apart.

16. Other Requirements

a. Protection of subsystem from magnetic fields and radiation levels greater than those listed under Section V-A-1-2, Environmental Requirements.

b. Acoustic decoupling of subsystem; separate acoustic sensor and spacecraft.

2. Instrumentation Subsystem for Operation Beneath the Lunar Surface

1. General Functions and Dimensions.[6] Covers instrumentation subsystem for downhole use or to be driven slowly into lunar surface. Weight estimates are for instrumentation system only and do not include holemaking or driving mechanisms.

[6]Over-all dimensions: 1-1/2-in. diameter, 18-in. length (see Fig. 3).

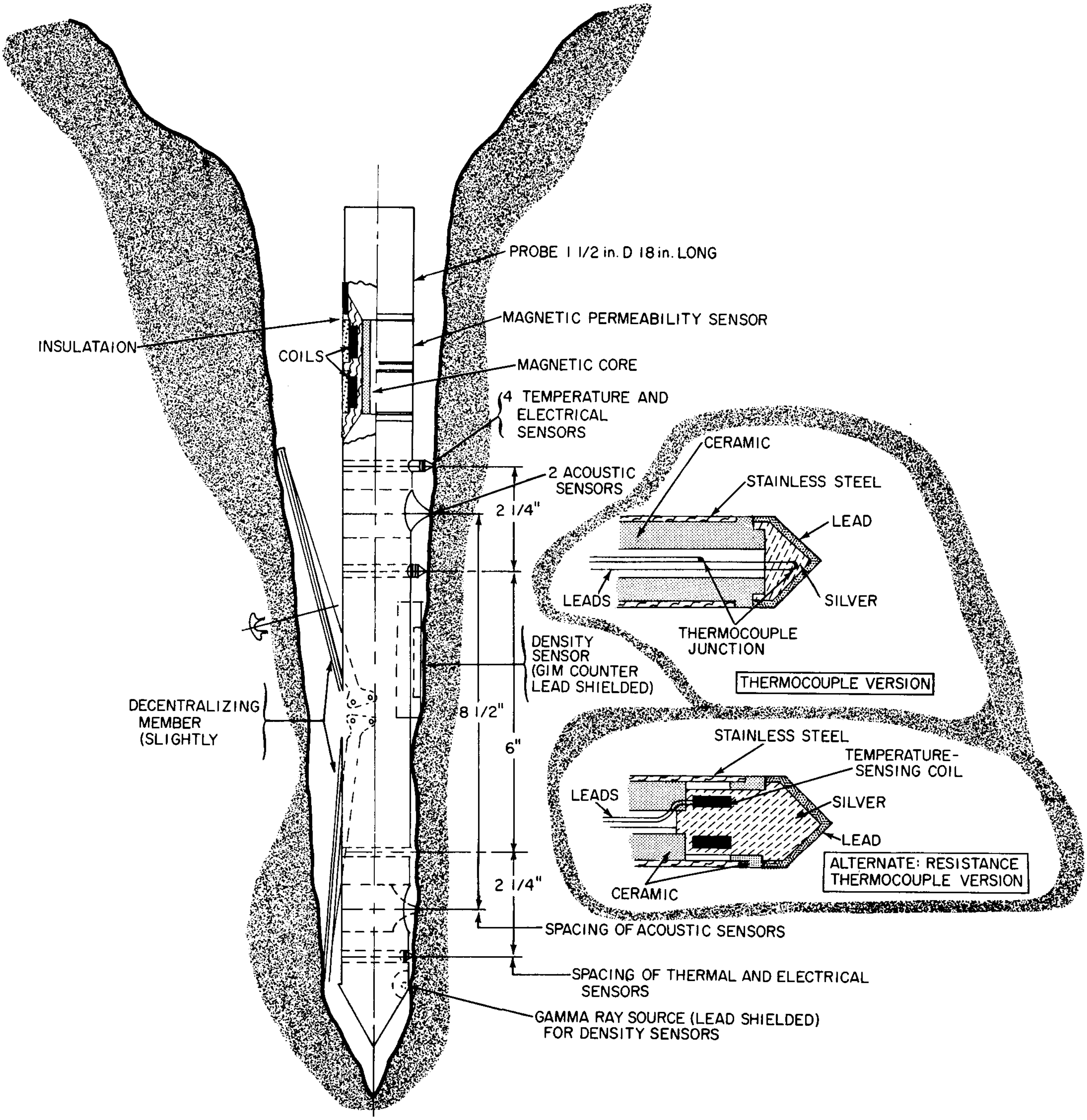

Fig. 3. Functional Diagram of Instrumentation Subsystem for Operation Beneath the Lunar Surface.

a. Density measurement: Utilizes the same method as given in the preceding section (1-1-a), a short-spaced, radioactive source and GM counter shielded against direct pickup, detecting back-scattered gamma radiation.

b. Acoustic velocity measurement: The acoustic velocity (compressional wave) is determined by measuring the acoustic travel time between two spaced, piezoelectric transducers coupled to the formation.

c. Magnetic permeability measurement: A mutual inductance technique is proposed using two small, powdered core coils with 10- to 20-millihenry mutual inductance and statically shielded. One coil is fed a constant current and the pickup voltage from the other will be proportional to the magnetic permeability of the surrounding formation.

d. Resistivity measurement: A four-electrode, short-spaced contact technique is used wherein two current electrodes are positioned outside two pickup electrodes. An alternating current is applied to the body through the current electrodes. The potential drop observed across the inner pickup electrodes is proportional to resistivity.

e. Temperature measurement: A thermocouple junction is contained in each of the four lead resistivity electrodes (see "resistivity measurement" above) to measure temperature at four depths. Four more thermocouples are mounted on the insulators carrying the first four to indicate conduction losses of the latter.

f. Hardness measurement: Although the drilling of the hole is the primary technique for measuring hardness characteristics, alternative techniques are being considered. One of these simulates the scratch hardness test. The sensor for this measurement consists of a series of parallel, electrically conductive bars of differing hardness mounted on the legs of the spacecraft. Change in resistance of the bars caused by scratching the lunar surface will indicate hardness of the materials encountered on landing.

2. Environmental Requirements

   a. Operating environment: Subsystem designed to survive lunar environment as specified in TM 33-13, with the following additional constraints:

      (1) Radiation environment: 0.8 milliroentgen per hour or less at the density device.

      (2) Magnetic field environment: 0.01 gauss or less at the upper end of probe.

   b. Nonoperating environment: Same as operating environment.

3. Weight Breakdown[7]

   a. Density: 0.25 lb.

   b. Acoustic velocity: 0.48 lb.

   c. Magnetic permeability: 0.30 lb.

   d. Resistivity: 0.17 lb.

   e. Temperature: 0.17 lb.

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[7]Probe sensor weight: 1.2 lb; probe structure weight: 0.8 lb; probe decentralizing device weight: 6 oz (last item included for down-hole application only).

4. Total Weight. 2 lb 6 oz for down-hole probe (excluding leads to the probe), or 2 lb total for slowly driven probe.

5. Required Orientation

   a. In prepared hole: Vertical alignment of probe and lowering into prepared hole.

   b. Slowly driven (soft material): Vertical alignment into local surface and slow driving into surface to a minimum depth of 18 in.

6. Required Knowledge of Orientation

   a. Prepared hole: Must know if probe is in hole and how deep.

   b. Slowly driven: Depth of penetration and alignment with local vertical. Depth to 0.5 in.; angle to 3 deg.

7. Operating Power

   a. Density: Requires 680-v dc regulated to 5%, 0 to 10 μamps. Maximum peak-to-peak ripple of 2%. Internal impedance of power supply of 3.4 megohms.

   b. Acoustic velocity: Requires 5000-v dc ±20% (choice of voltage within ±20% will affect data output) with maximum peak-to-peak ripple of 25 mv, charging a 0.005-mfd capacitor in 0.3 sec. Internal impedance of power supply, 5×10^9 ohms, peak drain of 1.0 μamps.

   c. Magnetic permeability: Requires 500-v ac ±20%, regulated to 2%, 400 cps, 10 milliamp (constant load). Internal impedance of power supply, 1000 ohms.

   d. Resistivity: Requires 500-v ac ±20%, regulated to 2%, 400 cps, through 50 megohms. Internal impedance of power supply, 1000 ohms.

e. Temperature: Fixed temperature box for reference thermocouple with 5 mv dc regulated standard. Fixed temperature box will be supplied. Characteristics of 5 mv dc regulated standard to be supplied by Spacecraft R:

nominal open circuit output voltage	4 to 6 mv dc
maximum departure from nominal open circuit voltage	±1%
internal impedance	less than 0.1% of impedance of detecting circuit
maximum drain	depends upon impedance detecting circuit
ripple and noise	50 mv peak-to-peak maximum within pass band of detecting circuit

8. Time per Operating Period

a. Density: 3 min.

b. Acoustic velocity: 11 sec (0.3 sec to charge capacitor, 150 μsec maximum travel time, 10 sec receiver on only to observe background). Repeat 10 times per operating period; 110 sec total.

c. Magnetic permeability: 60 sec (30 sec with power off, followed by 30 sec with power on).

d. Resistivity: 60 sec (30 sec with power off followed by 30 sec with power on).

e. Temperature: 7 min (30 sec for each measurement giving 14 samples).

9. Number of Operating Periods

a. Density: Every 12 hours for expected lifetime.

b. Acoustic velocity: Every 12 hours for expected lifetime.

c. Magnetic permeability: Every 12 hours for expected lifetime.

d. Resistivity: Every 12 hours for expected lifetime.

e. Temperature: Every 12 hours for expected lifetime and continuous measurement over day/night and night/day transitions (3-hour periods centered around sunset and sunrise).

10. Sample Preparation Requirements. None.

11. Manipulation Requirements

a. In prepared hole:

(1) Alignment of probe over the hole.

(2) Lowering of probe into the hole.

b. Slowly drive probe:

(1) Vertical alignment of probe at surface.

(2) Slow driving of probe into surface to a minimum depth of 18 in.

12. Data Output. This is based on nominal voltages given in 7. If other voltages within specified ranges are chosen, data outputs must be adjusted accordingly.

a. Density: 1 data output.

(1) Sensor output: 10 volt peak negative pulses of 90-μsec duration. 60 to 3600 pulses/sec rates correspond to 3.0 and 0.5 gm/cc density.

(2) Associated accuracies:

(a) Input impedance: 1 megohm minimum.[8]

(b) Over-all system accuracy: ±10%.[8]

---

[8]Input impedance refers to input impedance to the spacecraft data handling system, and over-all system accuracy refers to all errors introduced between the data output of the sensor and the data received on Earth.

(c) Dynamic range: 60 to 1.

(d) Maximum peak-to-peak wide-band noise: 1000-mv input reference.

b. Acoustic velocity: 1 data output.

(1) Sensor output: 5 mv peak, 160-kc wave train. Acoustic transmitter pulse initiates linear bootstrap generator. First quarter cycle of wave-train arrival at receiver stops generator. The instantaneous bootstrap amplitude is then a measure of travel time.

(2) Associated accuracies:

(a) Input impedance: 1 megohm minimum.

(b) Over-all system accuracy: ±2%.

(c) Dynamic range: 5 to 1.

(d) Maximum peak-to-peak noise: Such as not to detract from system accuracy given over expected life span.

c. Magnetic permeability: 1 data output.

(1) Sensor output: 250 to 1370 mv, 400 cps.

(2) Associated accuracies:

(a) Input impedance: 1 megohm minimum.

(b) Over-all system accuracy: ±5%.

(c) Dynamic range: 5 to 1.

(d) Maximum peak-to-peak noise: 10 mv input reference.

d. Resistivity: Time sequence sampling of 2 data outputs. Data output 1 (current electrodes):

(1) Sensor output: 1 to 100 mv, 400 cps.

(2) Associated accuracies:

(a) Input impedance: 1 megohm minimum.

(b) Over-all system accuracy: ±3%.

(c) Dynamic range: 100 to 1.

(d) Maximum peak-to-peak noise: 30 μv input reference.

Data output 2 (pickup electrodes):

(1) Sensor output: 0.4 to 30 millivolts, 400 cps.

(2) Associated accuracies:

(a) Input impedance is 2 megohms ± 0.1%.

(b) Over-all system accuracy is ± 3%.

(c) Dynamic range is 75 to 1.

(d) Maximum peak-to-peak noise is 12 μv input reference.

e. Temperature: Time sequence sampling of 14 data outputs.

(1) Sensor output (14 outputs): 50 μv/°C difference.

(2) Associated accuracies:

(a) Input impedance: 1 kohm minimum.

(b) Over-all system accuracy: ±0.5% (should correspond to 1°K).

(c) Dynamic range: 285 to 1.

(d) Maximum peak-to-peak noise: 1 μv input reference.

13. Real Time Data Storage. None.

Data storage is acceptable if accuracies given in paragraph 12 are maintained.

14. Commands Required from Spacecraft

a. In prepared hole:

(1) Orientation of probe.

(2) Placement of probe.

(3) Expansion of probe decentralizing device and release of sensors (one command to initiate internal sequence).

(4) Initiation of data sampling and storage sequence. (Include input power switching described in following paragraph 15 for resistivity, magnetic permeability, and acoustic velocity measurements.)

b. Slowly driven probe: Replace paragraphs a-1, 2, 3 by orientation and slow driving into surface.

15. Operational Sequence for Nominal Instrument Subsystem

a. In prepared hole:

(1) Orientation of probe over hole.

(2) Lowering of probe into hole.

(3) Expansion of probe to establish coupling by release of decentralizing device and sensors.

(4) Perform thermal measurements for 7 min (14 channels required).

(5) Measure resistivity with power off for 30 sec.

(6) Measure resistivity with power on for 30 sec.

(7) Measure magnetic permeability with power off for 30 sec.

(8) Measure magnetic permeability with power on for 30 sec.

(9) Measure density for 3 min.

(10) Measure output of acoustic receiver for 10 sec.

(11) Charge condenser for acoustic source for 0.3 sec.

(12) Discharge condenser and measure acoustic velocity; 150 μsec maximum measured time interval.

(13) Repeat steps (10), (11), and (12) nine times.

(14) Repeat steps (4) through (13) at 12-hour intervals for spacecraft lifetime.

(15) Stop all measurements except temperature one hour before day/night transition period.

(16) Record temperature measurements continuously for 3-hour period centered around sunset.

(17) Repeat steps (4) through (13) immediately following day/night transition and every twelve hours thereafter until start of night/day transition period.

(18) Repeat steps (16) and (17) for 3-hour period centered around sunrise.

(19) Repeat steps (4) through (13) at end of night/day transition.

b. Slowly driven probe:

(1) Vertical orientation of probe on surface.

(2) Drive probe into surface to a minimum depth of 18 in.

(3) Measurements made according to steps (4) through (19) given in preceding sequence for down-hole probe.

16. Other Requirements. Tolerable force for slow insertion of probe is 850 lb applied to the upper end of cylindrical probe.

B. Lunar Body Measurements

Seismic and gravimetric measurements are the most powerful tools available for determining the properties of the Moon as a body. The following data applies to a combined seismic and gravimetric experiment consisting of a three-component long-period seismometer, a short-period vertical seismometer, and a three-component servo system designed to constantly realign the three-component long-period seismometer. Monitoring of the response of the servosystem over a one-month period will give lunar gravity tide data. This combined experiment is described in paragraph 1 which follows. Paragraphs 2 and 3 describe two degradations of this system which require less spacecraft capability, but are meaningful scientific experiments.

1. Combined Seismic and Gravimetric System

General Functions and Dimensions. Transducers, ≤ 600 cubic in., approximately cylindrical in shape, with 8.5-in. diameter and 10-in. height. Consist of short-period vertical seismometer, 3-component long-period seismometer, and associated servosystem for orientation of the 3-component long-period instrument. Amplifiers, ≤ 80 cubic in., approximately 8 by 3 by 3 in. box. Consist of 4 amplifiers associated with the 4 seismic sensors (1 vertical short period and 3-component long period).

2. Environmental Requirements. Transducers and amplifiers require temperature range of -40 to 70°C. Tight temperature control required by gravimetric application will be supplied by the instrument. No other requirements not covered in TM 33-13 are necessary. Radiation and magnetic field environments are not a problem for this instrument. Nonoperating environment is the same as operating environment.

3. Weight Breakdown

   a. 3-component long-period seismometer, $\leq$ 20 lb (with servosystem).

   b. Short-period vertical seismometer, $\leq$ 10 lb.

   c. Amplifiers, $\leq$ 4 lb (4 at 1 lb each).

4. Total Weight: $\leq$ 34 lb.

5. Required Orientation: within 15 deg of the local vertical for the seismic transducers.

6. Required Knowledge of Orientation: within 15 deg. Servosystem within instrument will provide close alignment to local vertical.

7. Operating Power

   a. Transducers: Require 250 milliwatts continuously for lifetime of spacecraft plus 4 watt-hr available over a one-month period to be used by 3-component instrument for internal adjustments and to drive servosystem. Voltage range of 12 to 24 volts with ±5% accuracy in chosen voltage. This ±5% includes peak-to-peak total noise and ripple. Output impedance of power supply to be 400 ohms or less.

   b. Amplifiers: Require 400 milliwatts total (100 milliwatts per amplifier) continuously for lifetime of spacecraft. Voltage range of 12 to 24 volts with 12 volts preferred, ±5% peak-to-peak noise and ripple. Output impedance of power supply to be 400 ohms or less.

8. Time per Operating Period. Continuous over lifetime of spacecraft.

9. Number of Operating Periods. Continuous.

10. Sample Preparation Requirements. None.

11. Manipulation Requirements. Placement of transducer package on lunar surface with a designated face toward the surface.

12. Data Output. 7 outputs total.

    a. Three outputs from long-period instrument. Each one is as follows. Analog signal from 1/30 cps to 5 cps with ±5% accuracy in data received on Earth. 40-db minimum signal-to-noise ratio for each channel required. 50-db S/N preferred.

    b. One output from short-period instrument; analog signal from 1/10 cps to 10 cps with ±5% accuracy in data received on Earth. 40 db minimum and 50 db S/N preferred.

    c. Three outputs from servosystem associated with long-period instrument. Each output as follows: dc output of 10μv to 1 mv with $\pm1\mu$v accuracy in data received on Earth. Each output to be sampled for 30 sec every 15 min. Total sample for 3 outputs is 90 sec every 15 min.

13. Real Time Data Requirements. None.

14. Commands Required from the Spacecraft

    a. Uncaging signal after placement of transducer package on surface.

    b. Command to sample data from servo system.

15. Operational Sequence

    a. Placement of transducer package on surface in known orientation.

    b. Uncaging command and sequence.

    c. (1) Continuous recording of seismometer data for spacecraft lifetime.

       (2) Sampling of servo outputs every 15 min.

16. Other Requirements. The decision to place the transducers outside the spacecraft was made in order to provide a solution to the coupling and decoupling problems which appear most difficult if the device remains on the spacecraft.

The problem of temperature control from -40 to 70° C now remains and should be considered in the spacecraft design study. The weights, sizes, etc., quoted in items 1 through 15 do not contain allowances for such temperature control.

2. <u>Three-Component Long-Period Seismometer and Short-Period Vertical Seismometer</u>

Changes from 1

1. No change
2. No change
3. No change
4. No change
5. No change
6. No change
7. 4-watt hr reduced to 1-watt hr
8. No change
9. No change
10. No change
11. No change
12. Delete c. No output from servosystem measured.
13. No change

14. No change

15. Delete item c (2).

16. No change

3. Three-Component Long-Period Seismometer

Changes from 1

1. Delete 1 amplifier: Requires 60 cubic in., approximately 6 by 3 by 3 in. box.

2. No change

3. Delete item b. Change item c to 3 lb (3 at 1 lb each).

4. Change to: total weight, $\leq$ 23 lb

5. No change

6. No change

7. a. 4 watt-hr reduced to 1 watt-hr

   b. Change 400 mw total to 300 mw total.

8. No change

9. No change

10. No change

11. No change

12. Delete b and c.

13. No change

14. No change

15. Delete item c (2).

16. No change

C. Surface and Subsurface Composition Analysis

Three types of instruments are being considered for the composition analysis. Depending upon the weight for scientific instrumentation (see Section V-1), at least one, and perhaps several types of instruments would be used. Requirements for these experiments are as follows:

1. X-ray Spectrograph

1. General Functions and Dimensions. The X-ray spectrograph may be separated into two components: the X-ray detector head and the electronics package. Both components can be mounted inside the spacecraft vehicle. The X-ray head, a cylindrical tube 4 in. in diameter and 15 in. long (thus comprising a volume of about 185 cubic in.), contains an electron gun which excites the X-ray spectra, 18 dispersive analyzers, and two nondispersive proportional counters. The head contains preamplifiers for each counter. A reading port is located midway along the side of the head. A standard specimen is also included which may be put in and out of the sampling position.

   The electronics package may be separated into three rectangular boxes with dimensions of 5 x 6 x 9, 2 x 3-1/2 x 9, and 1 x 2 x 6 in., which makes a total volume of about 350 cubic in. In addition, a length of cable of cross-sectional area of 0.143 sq in. will be required to connect the X-ray head and the electronics package. The 1 x 2 x 6-cubic-in. package houses a high voltage supply and must be insulated for 30 kv from the rest of the vehicle.

The various components contained in the electronics package are the Geiger tube power supply, proportional counter power supply, 25-kv power supply, filament power supply, pulse height analyzer, and ground controlled switches.

2. Environmental Requirements

   a. Mechanical environment: During operation, mechanical shock and vibration of the vehicle should be kept to a low level.

   b. Temperature environment

      (1) Operative range: 50 to 70°C.

      (2) Non-operative range: 50 to 125°C.

      (3) A maximum variation in temperature, preferably less than 10°C is required for the 5 x 6 x 9 in. electronics package containing highly regulated proportional counter voltage supply during the period of operation.

   c. Sterilization environment

      (1) 24 hours at 125°C is acceptable.

      (2) 2 hours at 160°C is unacceptable (crystal decomposition).

      (3) 10^6 roentgen is unacceptable (degradation of components).

   d. Operating radiation environment: Less than 20 gammas per cm^2/sec.

3. Weight Requirements. The X-ray head weighs about 17 lb and the electronics package weighs 11 lb (possibly 15 lb). A 30-ft length of cable weighs about 4 lb.

4. Total Weight. The total weight excluding cable is 28 lb.

5. Orientation. During the sample analysis, the reading port should be 1/4 in. from the sample surface.

6. Required Knowledge of Orientation. There is no required knowledge of orientation.

7. Description of Operating Power. Present estimate is 16 watts total. Of this (1) 10 watts to be dc, preferably 12 volts, though 6 to 28 volts is acceptable; tolerance is ±1%. (2) 3 watts to be ac, 6 to 220 volts acceptable, 1 to 2.5 kc accpetable. (3) 3 watts to be ac, 26 volts required, tolerance ±1.5%, 2.1 to 2.4 kc acceptable.

8. Time per Operating Period (see Item 15)

9. Number of Operating Periods. The number of operating periods depends on the number of samples to be analyzed. About 6 samples will be counted. Also, two background and two standard specimen counts will be made. (See item 15.)

10. Sample Preparation. The nominal instrument requires a sample to be prepared. At least one sample from the surface is required. This sample should be acquired independently of the drill and must come from below the depth of possible surface contamination (1/32 in.) due to the vehicle. Powdered samples of mesh 100 to 300 weighing about 4 grams will give the best results. The sample should cover a circle of 1 in. in diameter and should be 1/8 in. deep; 1 lb per square inch compaction of the sample will be required to prevent scattering of the powder by the electron beam. About 5 samples, similarly prepared, should come from various depths in the drill hole.

11. Manipulation. The sample must be positioned opposite the reading port at no greater than 1/4-in. distance. Provision must be made for changing samples. The standard specimen will be inserted in the analyzing position from time to time to provide a check of the instrument.

12. Description of Data Interface. Both dispersive and nondispersive data are stored digitally in the 64-channel pulse height analyzer. The readout should be as rapid as the available bandwidth will allow (1024 sequential bits).

13. Real Time Requirement. Although some channels corresponding to high abundance elements will fill rapidly, there is no real time requirement. However, readout of any previous counting data must occur before a new sample may be counted or before another run may be made on the same sample.

14. Commands. The following commands are required from the central computer:

    a. Remove seal from sensing head port.

    b. Deliver and position samples.

    c. Remove sample.

    d. Standard specimen in.

    e. Standard specimen out.

    f. Geiger gate on.

    g. Geiger gate off.

    h. Readout of storage.

    i. Proportional counter gate on.

    j. Proportional counter gate off.

k. Select proportional counter No. 1, No. 2 off.

l. Select No. 2, No. 1 off.

m. Primary power on.

n. Primary power off.

o. Filament power on.

p. Filament power off.

15. Operational Sequence

a. Remove seal.

b. Turn on power (both primary and filament).

c. Count background with proportional counter No. 1. (About 2 min will be required.)

d. Readout.

e. Count background with proportional counter No. 2 (5 min).

f. Readout.

g. Standard specimen in.

h. Count with dispersive analyzers. Geiger gate open, proportional counter gate closed (less than 5 min).

i. Readout.

j. Count with proportional counter No. 1 (5 min).

k. Readout.

l. Count with No. 2 (5 min).

m. Readout.

n. Withdraw standard.

o. Position sample.

p. Count with dispersive analyzers (less than 1 min).

q. Readout.

r. Count dispersively (5 to 10 min).

s. Readout.

t. Count dispersively (30 min).

u. Readout.

v. Count with proportional counter No. 1 (about 1 min).

w. Readout.

x. Count with proportional counter No. 2 (about 5 min).

y. Readout.

z. Count with proportional counter No. 1 (about 5 min).

aa. Readout.

ab. Count with proportional counter No. 2 (about 5 min).

ac. Readout.

ad. Remove sample.

Steps (o) through (ad) will be repeated for each sample. The background and standard should again be counted as in steps (c) through (n) after the third sample has been counted (after step (62) .

16. Other Requirements: None.

2. <u>Neutron Activation</u>

1. General Functions and Dimensions.

This instrument can be separated into the following components:

a. A source sample chamber detector assembly which is a cylinder 3.75 in. in diameter and 47 in. long. This assembly must be separated from the spacecraft and the following components, while in operation, and just be adjacent to the "sample-packer" while the sample is being delivered.

b. A sample packing device which is essentially a cylinder 1.5 in. in diameter and 18 in. long. This device is attached to item a, with cylinder axes parallel while the sample is being delivered.

c. A power supply of 100 cubic-in. volume. This configuration is very flexible.

d. A pulse height analyzer of 300 cubic-in. volume. This configuration is also very flexible.

2. Environmental Requirements

a. Background radiation can be a source of interference, particularly if the level should be a factor of 3 above its normal lunar value.

b. For the units within the vehicle, the operating temperature limits are expected to be -10 to 70°C. For the extended cylinder the allowable temperature excursion will be 0 to 100°C. The nonoperative will be -50°C to 100°C.

c. Shock tolerance is given as 100 Earth g for 2.5 sec.

d. Vibration limits are given as 0 to 2000 cps at 15 Earth g with the noise type unspecified.

e. Dust should cause no interference as the unit is enclosed.

f. A magnetic field greater than 0.5 gauss at the detector could affect its performance.

g. Sterilization:

(1) 24 hr at 125°C is unacceptable (tube and crystal sterilized during manufacture).

(2) 2 hr at 160°C is unacceptable (tube and crystal sterilized during manufacture).

(3) Ethylene oxide is acceptable.

(4) 106 roentgen is unacceptable (severe damage to tube and crystal).

3. Weight of Components

a. Source-sample chamber-detector assembly: 21 lb.

b. Sample packing device: 1.5 lb.

c. Power supply: 3.6 lb.

d. Pulse height analyzer: 6 lb.

e. Cabling: 1.4 lb.

4. Total Weight: 33.5 lb

5. Orientation. To prevent substantial irradiation of the vehicle and subsequent interference with detection, it is necessary that the cylinder with the source be extended 15 to 30 in. from the vehicle so that it stands vertically with the source above the detector.

6. Knowledge of Orientation: None.

7. Description of Operating Power

a. Power supply: 48 watts. Preference is for 26 ± 10 volts, 2.4 kc, though either 115-volt, 60 cycle ac or 6 to 32-volt dc is acceptable.

b. Pulse height analyzer: 3 watts. Require 26 volt ±1.5%, 2.4 kc.

c. Photomultiplier power supply (located in detector cylinder): 0.5 watts. Require 6 to 32-volt dc ±1%.

d. Sample packing device: 1.5 watts.

8. Time per Operating Period. About 30 hr will be required for a complete cycle, with activation occurring for an integrated period of 10 hr, and the last 15 hr devoted solely to counting. The counting mode will require only 3-1/2 watts of power.

9. Number of Operating Periods. One per sample.

10. Sample Preparation Requirements. A granular or powdered sample of 16 mesh or finer is desired, with present estimates of quantity being 100 gm required and 200 gm desired.

11. Manipulation Requirements

a. A sample must be delivered to the sample packing device.

b. The source-sample-detector package must be extended.

c. If more than one sample is extended, provision must be made for repeated delivery. However, the number of samples which can be analyzed will be limited by the lifetime of the neutron source (probably not more than 30 hr).

12. Data Interface. Digital data will be stored in a 64-channel pulse height analyzer. Memory and readout (1024 bits) can occur at a rate compatible with the available bandwidth. The frequency of readout will be greatest early in the operating cycle, perhaps once every 3 to 5 sec, but can decline to once every 30 min late in the operating cycle (see item 15).

13. Real Time Data Requirement. Although a real time readout would be desirable for short half-lives, it will not be necessary.

14. Required Commands (not in order)

    a. Deliver sample.

    b. Remove sample (if more than one).

    c. Detector on.

    d. Detector off.

    e. Accelerator on.

    f. Accelerator off.

    g. Extend cylinder.

    h. Readout analyzer.

    i. Analyzer pulse train.

15. Operational Sequence. The sequence revolves around the following count--readout periods which will be repeated continuously.

    I. Count for 5 sec, read out 1024 bits in 1 sec.

    II. Count for 5 min, read out 1024 bits in 1 min.

    III. Count for 30 min, read out 1024 bits in 1 min.

    The fast 1-sec readout is required; the 1-min readout is acceptable for Modes II and III as an economy in transmission, but can be as fast as desired. The time sequence is:

    a. t - 0: Sample and unit are positioned.

    b. 0 - 30 min: Mode II, no neutron irradiation.

    c. 30 - 40 min: Mode I, irradiate.

    d. 40 - 50 min: Mode I, no irradiation.

e. 50 - 60 min: Mode I, irradiate.

f. 60 - 70 min: Mode I, no irradiation.

g. 70 - 80 min: Mode I, irradiate.

h. 80 - 90 min: Mode I, no irradiation.

i. 90 - 110 min: Mode I, irradiate.

(It is possible to interrupt the sequence at this point.)

j. 110 min - 6:30 hr: Mode II, irradiate.

k. 6:30 hr - 11:30 hr: Mode III, irradiate.

l. 11:30 - 11:50 hr: Mode I, no irradiation.

m. 11:50 - 16:30 hr: Mode II, no irradiation.

n. 16:30 - 26:30 hr: Mode III, no irradiation.

o. Remove sample, install new one, and repeat cycle.

16. Other Requirements. A rapid rate of temperature variation would be dangerous to the detector.

3. Mass Spectrometer

1. General Functions and Dimensions. The separable parts of the instrument are as follows:

   a. Source-analyzer package: 286-cubic-in. horseshoe shape, approximately 2.5 x 2.5 x 28 in. in diameter.

   b. Electronics: 6 x 6 x 2 in. (Separation from item a must be less than 12 in.)

   c. Power supply: 6 x 6 x 2 in.

2. Environmental Requirements

   a. The instrument will operate in an external field up to one gauss in any direction. Higher fields may be tolerated if known in advance.

   b. The instrument will operate properly during a 25°C excursion between 0 and 60°C. Nonoperating temperature will range from -40 to 70°C.

   c. The maximum operating pressure is 10^{-4} mm Hg.

   d. Shock or microphonic vibration is intolerable during operation.

3. Weight Breakdown

   a. Source-analyzer package: 19 lb.

   b. Electronics: 3 lb.

   c. Power supply: 4 lb.

   d. Cabling: 2 lb.

4. Total Weight. 28 lb.

5. Required Orientation. None.

6. Required Knowledge of Orientation. None.

7. Operating Power. This instrument contains its own power supply which provides the necessary regulated voltages. The spacecraft input to the power supply is 26 watts at 25 ± 4 volts dc. This includes power for the spark source.

8. Time per Operating Period. It is anticipated that one minute will be a reasonable time to take in scanning the complete mass spectrum (1 to 240 AMU). If required, it should be possible to use a scan time a few times slower or faster than this.

9. Number of Operating Periods. Six operating periods corresponding to six samples are presently required. The instrument has flexibility of continuous or intermittent operation on command.

10. Sample Preparation. One hundred milligrams of 400-mesh powder per sample is required. One sample acquired from the surface, independent of the drill operation, and five samples from various depths in the drill are required. Delivery is at one end of the "horseshoe."

11. Manipulation Requirements. Sample delivery to the instrument only.

12. Description of Data. The output of the scanning electronics consists of up to 240 gaussian shaped pulses, with amplitude ranging from 0 to 5 volts. It is not necessary to transmit the shape of these pulses; only the amplitude is significant. The time of occurrence, measured from the beginning of the scan, of a mass peak corresponding to a mass of M is given by $T = K \sqrt{M}$, where K is a constant. A system which gives 1% accuracy in the amplitude will require about 2500 cycles per scan. Therefore, under the assumption of a 60-sec scan time, the recording bandwidth for a 1% analog recording

system is approximately 2500/60 or forty cycles per sec. For good reliability, the scan should be repeated a number of times.

13. Real Time Data Requirements. There is no real time data requirement. There is no data storage included in the instrument package.

14. Commands from Spacecraft

    a. Initial command to excite instrument.

    b. Standby command.

    c. Turnoff command.

15. Operational Sequence

    a. Sample prepared and transmitted to instrument.

    b. Initial command to excite instrument.

    c. Immediate data output to telemetry system (about 1 min).

    d. Turnoff or standby command.

    e. Repetition of items a through d for each additional sample.

16. Other Requirements and Interactions. A magnetic field of 10 gauss at a distance of 1 in. will be produced by this instrument.

D. Particles and Fields

1. Magnetometer

The intent is to measure the strength and direction of the lunar magnetic field and its time variations, as well as magnetic fields caused by lunar ionospheric currents, and the lunar day/night variation associated with the interplanetary plasma. A flux-gate magnetometer with three orthogonal sensors is presently thought to be adequate for this purpose and is the instrument described below.

1. General Functions and Dimensions

   a. The sensors are separable from the electronics and require roughly a volume of 20 cubic in.

   b. The electronics require less than 300 cubic in. of volume which is highly flexible in geometry.

2. Environment Requirements

   a. Sensor temperature must remain between -50 and 100°C. The magnetic field at the sensor must be less than one gamma and must be known to an accuracy of 0.1 gamma along the axis of each sensor.

   b. Electronic operating temperature ranges from -10 to 50°C.

3. Weight of Components[9]

   a. Sensors: 0.6 lb.

   b. Electronics: 3 lb.

4. Total Weight. 3.6 lb excluding cabling.

5. Required Orientation. None.

6. Required Knowledge of Orientation. All sensor axes should be known to within 2 deg of a standard Moon-fixed coordinate system.

7. Description of Operating Power. 540 mw (90 ma at 6 volts). Voltage regulation to ±1%.

8. Time per Operating Period. Ten min.

9. Number of Operating Periods. All sensors should be sampled simultaneously at least once every Earth day, with the exception of two days on either

[9]No cabling weight is included.

side of the terminator when the sampling rate should increase to at least six sampling periods per Earth day. This operation should continue for the lifetime of the spacecraft on the Moon.

10. Sample Preparation Requirements. None.

11. Manipulation Requirements. Only those inherent in the satisfaction of the orientation and operating environment requirements.

12. Description of the Data Interface. The data output is a voltage analog for each field component. The voltage appears in a range from 1 to 6 volts continuous across 100K resistance. The data reproduction must allow at least 25-mv resolution of the original analog signal. The frequency range is dc to 3 cps. These data conditions apply to each sensor separately, i.e., three equivalent channels are required.

13. Real Time Data Requirements. No real time data requirement is necessary if an accurate time reference for the data is available. An accuracy of at least 1 min is necessary.

14. Commands Required from Spacecraft. It appears that no more than a simple turn-on command is necessary.

15. Operational Sequence

    a. Placement of sensors in required magnetic environment.

    b. Turn-on command to excite the instrument and electronics.

    c. Sampling sequence as described in item 9.

16. Other Requirements. None.

2. Plasma Probes

The purpose of this experiment is to analyze and monitor the low-energy charged particle radiation which reaches the lunar surface.

1. General Functions and Dimensions. This will be a single cubical unit, approximately 8 in. on an edge, which will contain both electronics and sensors.
2. Environment. The magnetic field at the instrument due to the spacecraft must be less than 100 gamma during operation. The operating temperature range is -40 to 120°C. Nonoperating temperature range is -50 to 150°C.
3. Weight of Components. Does not apply.
4. Total Weight. Seven lb.
5. Orientation Requirements. One face of the instrument must be normal to within better than 20 degrees of the local vertical and must have an unobstructed look-angle of approximately 2 pi steradians. (This look-angle should not be reduced by more than 10%.)
6. Required Knowledge of Orientation. The orientation must be known to within plus or minus 2.5 deg.
7. Description of Operating Power. Less than 1/2 watt.
8. Time per Operating Period. Ten min.
9. Number of Operating Periods. This instrument must be sampled at the same time that the magnetometer is sampled. The number of operating periods is therefore the same as that for the magnetometer.
10. Sample Preparation Requirements. None.

11. Manipulation Requirements. Only those necessary to achieve the desired environment and orientation.

12. Description of the Data Interface. Approximately 1000 bits per 10 min operation.

13. Real Time Data Requirements. These are identical with those of the magnetometer.

14. Commands Required from the Spacecraft. Turn-on and turn-off commands appear sufficient.

15. Operational Sequence.

    a. Placement of instrument to satisfy environment and orientation.

    b. Turn-on command.

    c. Sampling sequence as described in item 9.

16. Other Requirements. None.

3. Particle Detectors

The present purpose of carrying particle detectors on *Surveyor* is to aid in the interpretation of other experiments.

It is clear that much of the instrumentation needed for such detection already exists for the purposes of other experiments. An example is the pulse height analyzer and counter voltage supplies of the X-ray spectrograph.

It is possible that a simple change of mode command with a data output rate consistent with any residual capacity in the telemetry system will prove sufficient for the *Surveyor* mission. As the integration and definition of other experiments proceed, any necessity for additional sensor or electronic elements will become clear. The requirements for such additional instrumentation should be minimized.

E. Lunar Atmosphere

The atmosphere measurement presently considered is performed by a "Redhead" ionization gauge. The result expected is both the total and the ion "pressure" at the lunar surface as a function of time.

1. General Functions and Dimensions

   a. The sensor and magnet package is a cylinder 11 cm in diameter and 10 cm long.

   b. The electronics (including power supply) package is quite flexible with respect to shape, with a volume of 13 cubic in.

2. Environmental Requirements. All components should operate in the temperature range from 0 to 50°C. Nonoperating temperature should remain between -40 and 100°C. The only other important environmental factor to consider at this time is the necessity of limiting the pressure due to contaminating gases. The sensor on one end of the cylinder can be considered to have a view of approximately one hemisphere. (This should not be reduced by more than 20%.) The influx of contaminating gases through the view angle should not contribute a partial pressure greater than 10^{-13} mm of Hg.

3. Weight of Components

   a. Sensor and magnet: 2 lb.

   b. Electronics: 1-1/3 lb.

4. Total Weight. 3-1/3 lb.

5. Required Orientation. No orientation is required other than that which may be desirable for satisfying the pressure environment and sensor view angle.

6. Required Knowledge of Orientation. None.

7. Description of Operating Power. 0.8 watt. Operating voltages are not known but will not be a critical item.

8. Time per Operating Period. This is essentially dependent on the telemetry system since the amount of information per operating period would be kept constant. The period over which the data are read out should not, however, exceed several minutes.

9. Number of Operating Periods. The operation should immediately precede, follow, or occur during the operation of the magnetometer and plasma probes. Therefore, the number of operating periods should be equivalent to that of the magnetometer and plasma probe.

10. Sample Preparation Requirements. None.

11. Manipulation Requirements. Only those which may be necessary to satisfy the pressure environment.

12. Description of Data. Less than 600 bits per operating period.

13. Real Time Data Requirements. These are identical with the requirements on the magnetometer and plasma probe.

14. Commands Required from the Spacecraft. These are identical with the plasma probe.

15. Operational Sequence. This is identical to the plasma probe.

16. Other Requirements and Interactions. There is a magnetic field associated with the instrument which should be less than 2 gauss at 12 in.

F. Organic Analysis of Lunar Subsurface (Biological Experiment)

The apparatus presently considered for this experiment is a gas chromatographic device which has just begun to receive detailed study. This device depends entirely upon the success of the drill for its proper functioning.

1. General Function and Dimensions. The entire analytical operation of separation and detection of volatile components from samples obtained in the sublunar surface will be performed in a single black box. The dimensions of the box will be approximately 8 by 8 by 10 in.

2. Environmental Requirements. The operating temperature range should be between 0 and 70°C. When the instrument is not operating, the temperature should not be less than -70 nor more than 150°C. Ionizing radiation should not exceed the ionizing capacity of the beta emission from a 30-millicurie strontium 90 source within the volume of the instrument during operation.

3. Weight of Components. Does not apply.

4. Total Weight. The total weight of the box will be less than 10.5 lb.

5. Orientation Required. The normal to any 8 x 10 in. plane should be within 15 deg of the local vertical.

6. Required Knowledge of Orientation. None.

7. Description of Operating Power. Both dc and ac electrical power will be required, but the total power requirements will not exceed 10 watts. The electrical characteristics are as follows: 8 watts anywhere from 18 to 30 volts dc with a variation no greater than 5% at the chosen voltage, 2 watts ac at an amplitude peak wave of 20 to 30 volts, frequency 3000 to 10,000 cycles

per sec with a tolerance of 25%, square waves with rise time of less than 2 μsec tolerance, and voltage fluctuation no greater than 25%.

8. Time per Operating Period. Thirty min per sample followed by 10 min of flushing during which no function will be required from the spacecraft.
9. Number of Operating Periods. This depends upon the number of samples that can be acquired. It will be less than 30 in any case.
10. Sample Requirements. One of the principal conditions of this experiment is that samples be obtained from beneath the lunar surface. Therefore, the success of this experiment appears to be uniquely dependent upon the presence and success of the lunar drill. As presently conceived, the optimal state of the sample shall be a granular form having dimensions which shall not exceed 1/4 in. and shall not be as small as to permit passage through a 500 mesh screen. The optimal mass of a single sample has not yet been determined, but is in the range of 1 to 5 grams. The sample should be delivered to the 2 in.-diameter circular entrance port which will be located at the top of and in the corner area of the box's 8 x 8-in. face. The residues after pyrolysis will be dumped into the interior of the box; thus, no provision is necessary for its disposal.
11. Manipulation Requirements. Only those inherent in the sample preparation.
12. Description of the Data Interface. The data output will be a voltage from 1 to 5 volts. The reproducibility should be of the order of 1%. Four such channels will be utilized and must be monitored continuously during operation.
13. Real Time Data Requirements. None.

14. Commands Required from Spacecraft. Currently not defined, except for initiation and arrest of analytical cycle.

15. Operational Sequence. The general operational sequence as currently foreseen includes the following:

    a. Command from spacecraft to begin analytical cycle.

    b. Preparation of instrument.

        (1) Electronics on.

        (2) Thermal control system on.

        (3) Port opens to receive sample.

    c. Introduction of sample or control to chamber by external devices.

    d. Sample chamber inlet port closes and seals.

    e. Flash heating of sample by thermite pellet to volatilize and pyrolize organic matter in sample.

    f. Concentrate volatile fraction of sample by a valve system.

    g. Purge volatile sample into absorption columns by opening outlet port of carrier gas tank and inlet valves to absorption columns.

    h. Thirty-min period of data recording, monitor column temperature carrier gas inlet and exhaust pressures and the detector signals.

    i. Flush column with carrier gas for 10 min.

    j. Carrier gas flow turned off.

    k. Discard crude, pulverized fraction from chamber.

    l. Instrument off.

Above cycle will be repeated upon command signal from spacecraft.

16. Other Requirements and Interactions. Magnetic fields will be produced by a permanent magnet motor. If unshielded, it will produce 20 to 30 gauss at a 6 in. diameter; if shielded, however, complete shielding can be obtained at the site with a weight increase of 1/2 lb. Thirty mC of strontium 90 is located in the box. At present, position within the box and shielding properties of the box are not determined and will not be determined during the course of this study.

VI. PREFERRED INSTRUMENTATION

As stated in the instrumentation sections, the following order of instrumentation is for the purposes of the design study and changes to it can be expected.

In general, weights will not be mentioned in this section since such information is either given as part of the requirements in Section V or is implicit in the requirements of Section IV.

The preferred instrumentation, as a function of increasing spacecraft capability, is as follows:

1. The lunar geophysical surface and subsurface measurements: Section V, p. 13.

   The TV System: Section IV, p. 9.

   The X-ray spectrograph: Section V, p. 41.

The items that follow are now successive additions to all the previous instrumentation.

2. The drill: Section IV, p. 10.
3. The gas chromatograph: Section V, p. 61.

4. The minimal seismometer: Section V.
5. The magnetometer and plasma probes: Section V, pp. 54, 57.
6. An improved TV system capable of 0.1 to 0.01 mm resolution of a few selected areas in the vicinity of the spacecraft: Section IV, p. 9.
7. The particle detectors: Section V, p. 58.
8. The seismometer (replaces item 4): Section V, p. 36.
9. The best seismometer and gravimeter experiment (replaces item 4 and item 8): Section V, p. 36.
10. The neutron activation apparatus: Section V, p. 46.
11. The ionization gauge: Section V, p. 59.
12. An improved TV system with extensions to the ultraviolet and infrared spectrums.
13. The mass spectrometer: Section V, p. 52.
14. Any additional capability should be used to improve the drill, to improve sample acquisition, and to improve TV systems.